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River control and the evolution of knowledge: a comparison between regions in China and Europe, c. 1400–1850[1]

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Abstract
This article examines the similarities and divergences in the evolution of knowledge concerning river control in China and Europe, between about 1400 and 1850. The analysis concentrates on four densely populated and relatively prosperous regions, which were faced with comparable problems caused by unruly rivers: the coastal plains of the Yellow River, the basin of the middle Yangzi, the coastal area of Northern Italy, and the Rhine delta in the Netherlands. During the period under discussion, Northern Italy was the first region to witness a 'cognitive leap' in knowledge of river hydraulics. The author analyses why this particular transformation in the body of knowledge took place in Northern Italy, rather than in any of the regions in China. He also examines why the Netherlands, in contrast to regions in China, offered a receptive environment to this new approach in river hydraulics from c. 1770. He suggests that differences in the development of knowledge can be explained primarily in terms of underlying socio-political structures.

Introduction

'Since European rivers presented few serious control problems, European interest [in hydraulic works], when eventually it arose, centred mainly on transport canals', Joseph Needham many years ago claimed in his magisterial *Science and civilisation in China*.[2]

1 An earlier version of this essay was presented at the Global Economic History Network Conference in the Netherlands Institute of Advanced Studies, Wassenaar, The Netherlands, September 2004. I am grateful to the participants of this conference and the referees of this journal for their very helpful comments and to Jaap Fokkema for drawing the maps.

2 Joseph Needham, with Wang Ling and Lu Gwei-djen, *Science and civilization in China*, vol.4.III, *Civil engineering and nautics*, Cambridge, Cambridge University Press, 1971, p. 376; Needham was nevertheless aware of the emergence of what he calls 'post-Renaissance mathematical hydrodynamics', see footnote on p. 231.

In contrast with China, European countries apparently developed no particular interest, or competence, in the management of water flows in rivers. Anyone who has kept up with the news of the last ten years or so knows that Needham's remark was in fact rather optimistic, to say the least. European rivers like the Rhine or the Elbe *do* present serious control problems today and, the historian may add, they did so in the past as well. Problems of river control in Europe are less different from those in China than a casual glance might suggest. Like China, Europe in course of time saw the growth and application of a extensive body of knowledge designed to understand and, ideally, to improve the control of unruly rivers. The period between *c.* 1400 and the middle of the nineteenth century was of pivotal importance in this particular domain of knowledge both in China and in Europe.

This essay examines the similarities and divergences in the evolution of knowledge on river control in China and Europe between about 1400 and 1850. The analysis concentrates on four densely populated and relatively prosperous regions which were faced with comparable problems caused by unruly rivers: the coastal plains of the Yellow River (Huang Ho), the basin of the middle Yangzi, the coastal area of Northern Italy and the Rhine delta in the Netherlands. Each of these four regions was highly vulnerable to recurrent calamities produced by the turbulent behaviour of rivers forcing their way in from a mountainous hinterland. Although the 'base lines' in these regions around 1400 were in many respects similar, the evolution in the creation and diffusion of knowledge on river control in the following centuries diverged markedly. Why was that? The argument in this article will concentrate on the development of distinct forms of knowledge, the operation of transmission mechanisms within and between these regions and the paramount role of underlying socio-political structures. By including two different regions on the Chinese and European sides of the comparison, this essay also aims to provide a more solid and balanced basis for conclusions about the similarities or differences in the development of 'useful' knowledge in China and Europe in general.

The opening section of this article describes the nature of the fluvial problems with which people in the four regions in China and Europe had to cope and takes a comparative view of the development of river management. How did people in these regions actually attempt to get unruly rivers under control? The next section analyses the differences in the development of knowledge on river hydraulics in the four regions under discussion and highlights the singular 'cognitive leap' which occurred in Northern Italy during the seventeenth century. I then deal with the question of why this particular transformation in the body of knowledge took place in Northern Italy rather than in any of the regions in China, and why the Netherlands, in contrast to the two regions in China, offered a receptive environment to this new approach in river hydraulics from about 1770 onwards. The thesis I will defend here is that these differences in the development of knowledge primarily can be explained by underlying socio-political structures. The conclusion will summarize the results of this essay in comparative global history and briefly discuss what inferences can be drawn from this case-study in river hydraulics about the development of 'useful' knowledge in Europe and China in general.

Controlling wild rivers

Through the ages, the Yellow River has been notorious for the massive amounts of silt which it carries from the loess plateau in Northwest China to the sea, and for the wide seasonal fluctuations in its flow. During its traverse of the upland plain of Shaanxi and Shanxi, the river receives large quantities of yellowish mud, which it partly deposits on its bed in the lowlands of Henan, Hebei, Anhui, Jiangsu and Shandong and partly at its mouths in the gulf of Bohai (or formerly, in the Yellow Sea). The steady rise of the river bed, which in the past has proceeded at a rate of about 3 feet per century,[3] frequently causes the river to overflow its banks and sometimes to seek new routes to the sea. In the late twelfth century, the Yellow River switched course to stream south, instead of north, of the Shandong peninsula, and in the mid-nineteenth century it changed back again to flow out in the gulf of Bohai. The troubles caused by the continued, massive sedimentation are aggravated by the sharp variations in the size and speed of the river's flow over the year. Sudden, heavy rainfall during the summer months can turn the sluggish stream overnight into a torrent, which cannot easily be contained within its banks. Flooding by the Yellow River has been a regular occurrence throughout most of China's history. The problem of managing this river was, since the early fifteenth century, further complicated by the reconstruction of the Grand Canal, connecting the southern provinces with the capital Beijing, which crossed the Yellow River and included part of its lower course. The key issue was to find a way both to contain the Yellow River and to keep the junctions with the canal in operation (Fig. 1).[4]

In the case of the Yangzi, which carries large amounts of silt, too, the main bottleneck lies in the middle course of the river, in the plains of Hubei, Hunan and Jiangxi. The fall is feeble, the body of water is swollen by the confluence with the river Han from the North and various smaller streams from the South, and the outlet to the East is extremely narrow. Flooding in these parts of China became an ever greater menace from the eighteenth century onwards, when due to clearances in the hinterland of Sichuan and Shanxi the amounts of silt carried by the rivers grew substantially, while the free flow of water was increasingly hampered by dike building and the formation of sandbars. Moreover, the size of the natural reservoir on the southern side of the plains, Lake Dongting, significantly diminished as a result of land reclamation (Fig. 2).[5]

Whereas rivers in Northern Italy neither bring down as much silt as the Yellow River and the Yangzi in China, nor show such violent fluctuations over the year, sedimentation and torrential flows have nevertheless caused serious problems, especially in the plains of

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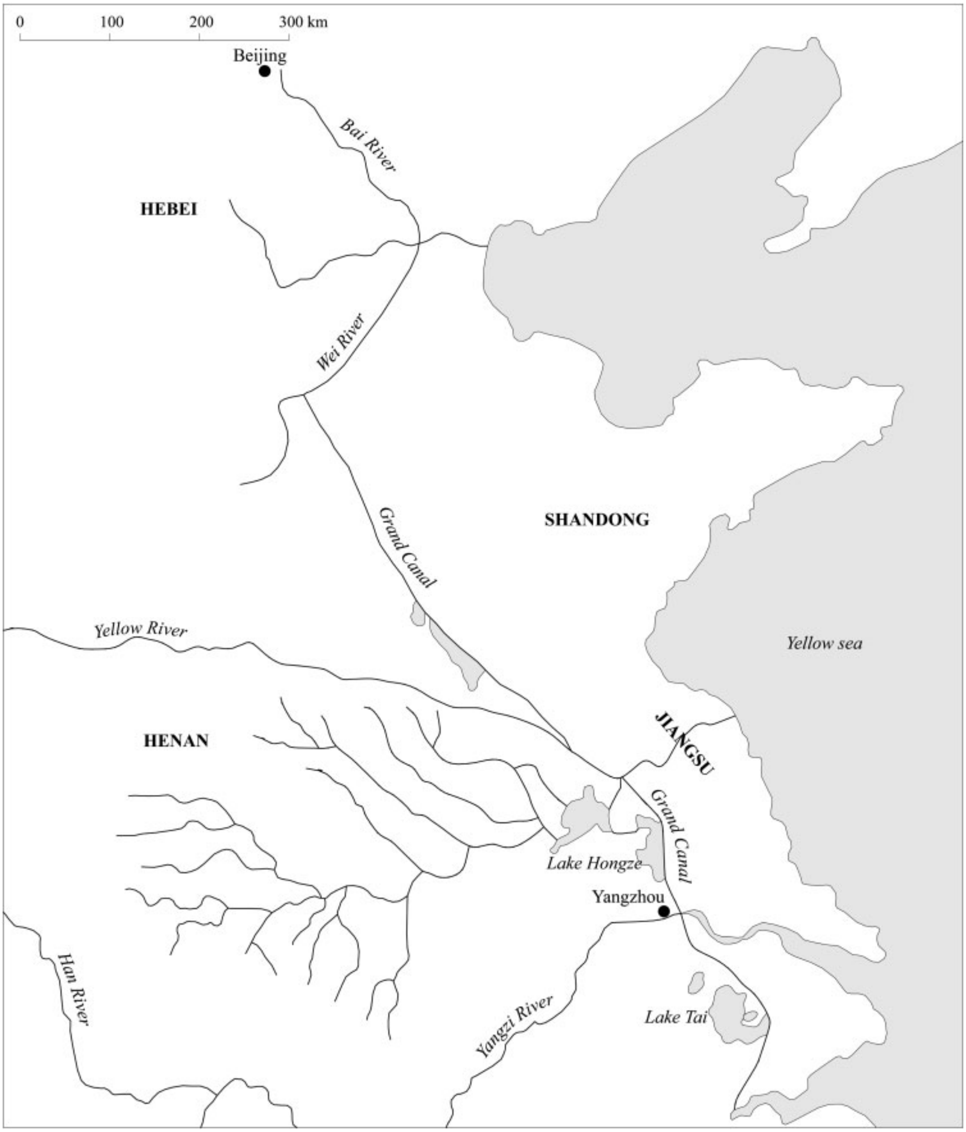
3 Needham, *Science and civilisation*, p. 237.

4 K. Flessel, *Der Huang-ho und die historische Hydrotechnik in China*, Tübingen: Eigenverlag, 1974, pp. 7–10, Mark Elvin, *The retreat of the elephants. An environmental history of China*, New Haven: Yale University Press, 2004, pp. 23–6, 128–32, Randall A. Dodgen, *Controlling the Dragon. Confucian engineers and the Yellow River in Late Imperial China*, Honolulu: Hawaii University Press, 2001, pp. 11–13; for a general picture see also Mark Elvin, H. Nishioka, K. Tamaru, and J. Kwek, *Japanese studies on the history of water control in China: a select bibliography*, Canberra: Australian National University, 1994.

5 Pierre-Étienne Will, 'Un cycle hydraulique en Chine: la province du Hubei du XVIe au XIXe siècles', *Bulletin de l'École Française d'Extrême Orient*, 58, 1980, pp. 262–8, 279, 282–5; Frank C. Perdue, 'Water control in the Dongting Lake region during the Ming and Qing periods', *Journal of Asian Studies*, 41, 4, 1982, pp. 747–8, 757–9; Anne Rankin Osborne. 'Barren mountains, raging rivers. The ecological and social effects of changing landuse on the Lower Yangzi periphery in Late Imperial China', PhD Thesis, University of Columbia, 1989, pp. 42, 212–13.

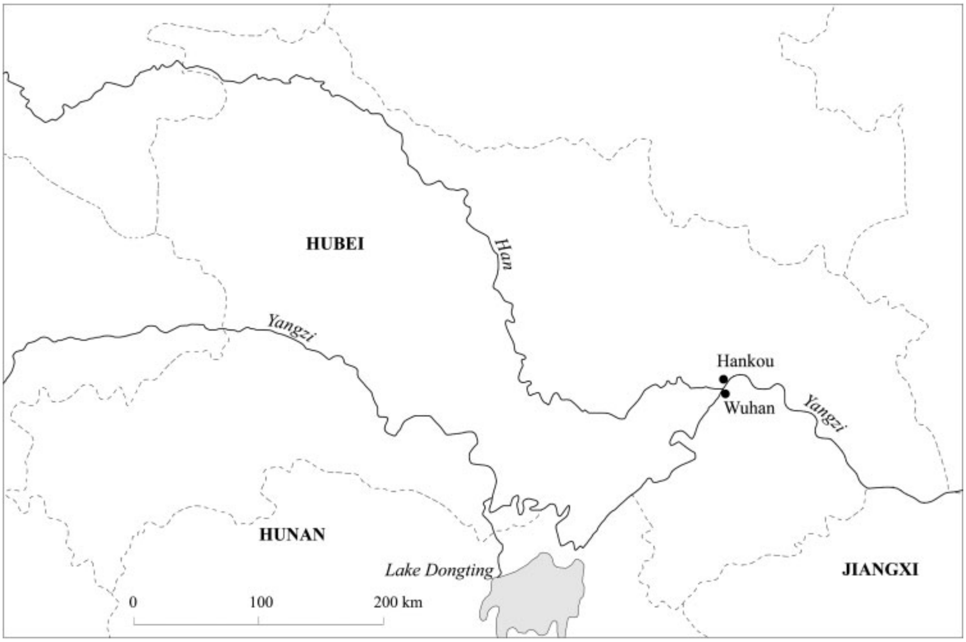
Figure 1. The coastal plains of the Yellow River and the Grand Canal.



the Veneto and the Emilia-Romagna, where numerous larger and smaller streams converge towards the Adriatic Sea.[6] In the lowlands of the Veneto, large amounts of silt carried by the Piave, Brenta, Musone, Sile and other rivers threatened to fill up the lagoon of Venice and its entrances, thus smothering the commercial lifeline of the Republic. The Adige at times conveyed such great quantities of water from the Alps that the river broke its banks

6 Salvatore Ciriacono, *Acque e agricoltura. Venezia, l'Olanda e la bonifica europea in età moderna*, Milan: FrancoAngeli, 1994, pp. 138–9, 162–4, 196–201; Franco Cazzola, 'Le bonifiche cinquecentesche nella valle del Po: governare le acque, creare nuova terra', in A. Fiocca, D. Lamberini, and C. S. Maffioli, ed., *Arte e scienza delle acque nel Rinascimento*, Venice: Marsilio, 2003, pp. 15–17; C. S. Maffioli, *Out of Galileo. The science of waters 1628–1718*, Rotterdam: Erasmus Publishers, 1994, pp. 24, 42–3, 156–8, 347, 371.

Figure 2. The basin of the Middle Yangzi (contemporary map).



and sought new courses in the low-lying lands of the Veneto. In the region to the south of the Po, hydraulic problems grew as the branch of this river called 'Po Grande' between the thirteenth and sixteenth centuries received an ever larger share of the water, depriving the branches of the 'Po of Ferrara' and the 'Po of Primaro' of much of their inflow, thereby speeding up the process of silting. This obstructed the access to the port of Ferrara and made it harder to control the river Reno running from the Apennines along Bologna to the Po (Fig. 3).

Like the coastal plains in Northern Italy, the Netherlands is at the receiving end of big rivers carrying a mass of water and silt from a mountainous hinterland to the sea. In this case, the usual problems of sedimentation and variations of the water flow over the year were compounded by incursions from the North Sea and by the interference between the rivers Rhine (entering the country from the East) and Meuse (entering from the South). The destruction of the Grote Waard polder southeast of Dordrecht by a disastrous storm tide about 1420 and the subsequent creation of a large, permanent waterlogged area called the Biesbosch, led to a displacement in an upstream direction of the mouth of one of the branches of the Rhine, called the Waal, which increased the Waal's fall and thereby influenced the distribution of the water of the Rhine over its various branches. This distribution was further disturbed by an accidental diversion of the river's course around 1530 near the point where the Rhine entered the Netherlands.[7] During the sixteenth and seventeenth centuries, the distribution of the Rhine's water in fact became more and more

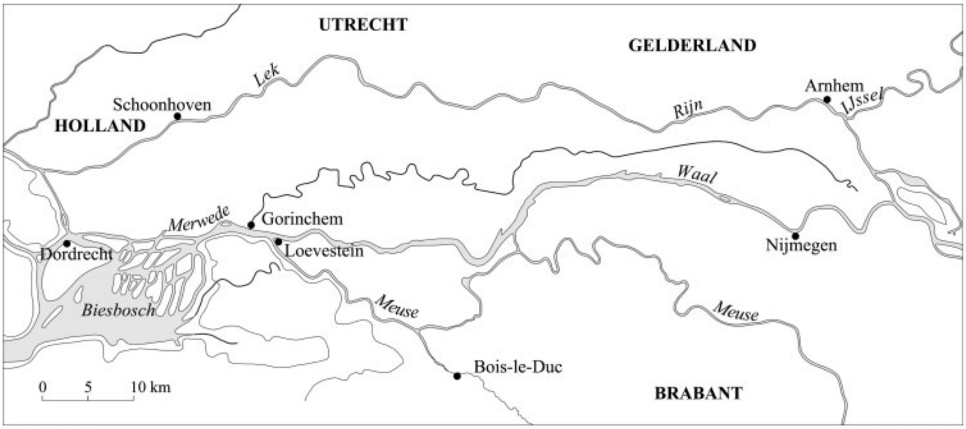
7 M. K. E. Gottschalk, *Stormvloeden en rivieroverstromingen in Nederland*, vol. II, Assen: Van Gorcum, 1975, pp. 96, 100, vol. III, Assen: Van Gorcum, 1977, p. 418. G. P. van der Ven, *Aan de wieg van Rijkswaterstaat. Wordingsgeschiedenis van het Pannerdens Kanaal*, Zutphen: Walburg Pers, 1976, p. 26.

Figure 3. The coastal plains of Northern Italy.

skewed, with the effect that by 1700 some 90% of all the water of the Rhine, which entered the territory of the Dutch Republic near the fortress Schenkenschans, flowed into the river Waal, as against only 10% into the Lek and the IJssel. The consequence of this disproportionate distribution was that the water level in the Lek and the IJssel became so low (and silting increased to that extent) that shipping was often seriously hindered and the military defences of the Republic were gravely weakened, whereas the volume of water in the Waal grew so massively as to cause enhanced risks of flooding downstream. An even more complicated situation developed in the area between Gorinchem and Dordrecht, where the Maas first merged with the Waal into the Merwede at Loevestein, and the Merwede subsequently dispersed most of its water over the innumerable creeks of the Biesbosch. This peculiar combination of conditions on the one hand increased the risks of flooding and the formation of ice dams in wintertime in the region of Gorinchem, and on the other hand decreased the navigability of the river Merwede between the Biesbosch and Dordrecht (Fig. 4).[8]

8 Van der Ven, *Aan de wieg van Rijkswaterstaat*, pp. 24–7; G. P. van der Ven *et al.*, *Niets is bestendig . . . De geschiedenis van rivieroverstromingen in Nederland*, Utrecht: Matrijs, 1995, pp. 11–24.

Figure 4. The Rhine delta in The Netherlands.



To protect lands along the rivers from flooding, a common defensive measure taken in all four regions was the building of levees, dikes or embankments. Levees and embankments appeared along the Yellow River from the time of the Warring States onwards. During the Song period dike building started along the Yangzi in Hubei and around Dongting Lake in Hunan. Northern Italy and the Netherlands saw the first levees and embankments along rivers arise in the High or Late Middle Ages. Dredging as a means to combat silting began somewhat later. Mechanical dredgers spread in China from the time of the Song dynasty onwards. Dredging engines cleared the canals of Venice from the sixteenth century. They appeared on the river IJssel in the Netherlands not long thereafter.[9]

Offensive operations to control unruly rivers were to a varying extent undertaken as well. In the Yellow River basin, the most common method of managing the river from the late Song period until the late Ming was to subdivide its flow into various streams, by blocking outlets at some points and allowing it to pass at others. By the mid-1560s, the lower course of the Yellow River was said to consist of no fewer than sixteen channels.[10] In the late sixteenth century concerted efforts were made to solve the problems of river management in a radically different way, however, namely by re-unifying the river into a single course, and constricting its flow to a narrow channel ranged by a set of embankments, backed up by another set of dikes at some distance behind it (plus a number of spillways) to contain the overflow during periods of extremely high floods. The idea underlying this major reconstruction, designed by the Imperial Commissioner for the Yellow River Pan Jixun, was to let the river scour its own bed by increasing the speed of the current. After a brief reversal of policy during the last decades of the Ming, Pan's strategy was resumed

9 Dodgen, *Controlling the Dragon*, p. 16; Needham, *Science and civilisation*, pp. 336–7; Will, 'Un cycle hydraulique', p. 266; Perdue, 'Water control', pp. 752–4; Ciriacono, *Acque e agricoltura*, 216; J. Nanninga Uiterdijk, 'Een baggermachine van het jaar 1562', *Bijdragen tot de Geschiedenis van Overijssel*, 10, 1890, pp. 66–73; H. Conradis, *Die Nassbaggerung bis zur Mitte des 19. Jahrhunderts*, Berlin: Arbeitsgemeinschaft für Technikgeschichte des Vereins für deutsche Ingenieure, 1940, pp. 24–7.

10 Dodgen, *Controlling the Dragon*, p. 14; Elvin, *Retreat of the elephants*, pp. 132–5.

in the late seventeenth century and remained the principal model for projects of river control in the Qing period until the middle of the nineteenth century.[11]

In the basin of the middle Yangzi, the main strategy of river management since the late Song was to contain the flow of river water in a single bed by maintaining a system of dikes running for hundreds of kilometres on end and by closing the passages between the rivers and the spacious lakes in the plains. Sometimes the current was redirected by means of groynes in order to counteract the growth of sandbars that threatened to block the channel and thus enhanced the risk of flooding. Yet, these measures did not check the steady rise of the river bed by the deposition of silt, which by the middle of the nineteenth century made the Yangzi as threatening to its environment as the Yellow River.[12]

River control in the coastal plains of Northern Italy to some extent followed the same pattern as in the basin of the Yellow River. The threat of flooding by the river Adige was in the early modern period met by the making of embankments, the building of overflow structures and the multiplication of the number of channels by which the water could find its way to the sea. Around Venice, major operations were undertaken to divert rivers to outlets outside the lagoon. A new channel for the river Brenta, for example, leading the river to the south of the lagoon, was constructed in the early seventeenth century. The Piave was in the 1640s diverted into the river Livenza and, once the disastrous consequences of this project had become clear, was in the 1680s redirected to a new mouth at the village of Cortellazo north of the lagoon.[13] To facilitate the reconstruction of the channels of the Po of Ferrara and the Po of Primaro, the river Reno was in 1604 provisionally diverted into a marshy area south of Ferrara. The unintended result was that the Reno overflowed its banks, a large part of the plain between Ferrara, Bologna and Ravenna changed into a swamp and much agricultural land seemed to be irretrievably lost. After much discussion and planning, the problem was in the second half of the eighteenth century eventually solved by redirecting the Reno into the Po of Primaro.[14]

In the Netherlands, extensive works to solve the nagging problem of the distribution of water of the river Rhine over its three major branches, Waal, Lek and IJssel, were carried out in the eighteenth century. Piecemeal engineering to remedy the situation, which began around 1600, did not result in any durable improvement. In the end, the problem was permanently solved by making some drastic changes in the river bed between Schenkenschans and Arnhem. The strategy consisted of diverting the course of the river and constricting its flow. The construction of the *Pannerdens Kanaal* (1706–8), the *Bijlands Kanaal* (1776) and a massive groyne at the point of separation between the Waal and the *Pannerdens Kanaal* (1784) directed a larger flow of water into the Nederrijn instead of into the Waal. The flow from the Nederrijn into the IJssel was increased by the making of an intersection of the Pleij headland between Arnhem and Westervoort in 1773–5.

11 E. B. Vermeer, 'P'an Chi–hsün's solutions for the Yellow River problems of the late sixteenth century', *T'oung Pao* 73, 1987, pp. 33–67; Dodgen, *Controlling the Dragon*, pp. 18–22; Elvin, *Retreat of the elephants*, pp. 135–40.

12 Will, 'Un cycle hydraulique', pp. 266–9, 285–6; Perdue, 'Water control', p. 759.

13 Maffioli, *Out of Galileo*, pp. 62, 156–8, 371; Ciriacono, *Acque e agricoltura*, pp. 162–8.

14 Maffioli, *Out of Galileo*, pp. 42–4; idem, 'Italian hydraulics and experimental physics in eighteenth-century Holland. From Poleni to Volta', in C. S. Maffioli and L. C. Palm, eds., *Italian scientists in the Low Countries in the XVIIth and XVIIIth centuries*, Amsterdam: Rodopi, 1989, p. 245.

The net result of these adaptations was that the distribution of the water of the Rhine over its three branches by 1790 had changed to the extent that six-ninths of the total volume streamed into the Waal, two-ninths into the Lek and one-ninth into the IJssel.[15] The hydraulic works started in 1736, which were aimed at improving the navigability of the Merwede near Dordrecht, were discontinued a few years later, however, when the damming of the Biesbosch led, unexpectedly, to such a rise in the river's water level that the island itself on which the city was built ran the risk of being inundated.[16] Wholesale reconstructions of the lower courses of the rivers Waal and Meuse were not carried out until the second half of the nineteenth century.

Differences in the development of knowledge on fluvial hydraulics

All these efforts to control the flow of rivers in China and in Europe between *c*. 1400 and the early nineteenth century had in common that they were based on a body of knowledge about hydraulic phenomena, which was at least partly recorded in manuscript or print. It was in part verbalized or visualized. River management at this time in the four regions under discussion thus involved more than 'tacit' knowledge. Yet, the path of development of knowledge about river control was significantly different.

To analyse these differences, we can usefully apply some distinctions employed by Joel Mokyr in his *Gifts of Athena*. Mokyr distinguishes two types of 'useful' knowledge: 'propositional' and 'prescriptive'. The first type—'what' knowledge—encompasses all knowledge about natural phenomena and regularities. It can assume two forms, Mokyr explains: one 'is the observation, classification, measurement, and cataloguing of natural phenomena'; the other is 'the establishment of regularities, principles and "natural laws" that govern these phenomena and allow us to make sense of them'. 'Prescriptive knowledge', by contrast, is 'how' knowledge: it consists of techniques, or 'executable instructions or recipes' for ways to manipulate nature.[17]

What is most remarkable in the Chinese case is the predominance of a particular form of propositional knowledge up to the nineteenth century. Chinese hydraulic experts could draw on a vast stock of 'descriptions, classifications, measurements and catalogues' of phenomena related to the Yellow River which had accumulated over the years. Yet, there seem to have been certain limits to the evolution of this knowledge. As Randall Dodgen pointed out, technical training of these hydraulic experts was approached in a purely 'ad hoc' manner. Hydraulic engineers acquired their knowledge 'on the job from subordinates or from the writings of their predecessors'. Publication of books on river management was highly valued, to be sure. 'Those who wrote knowledgeably were lionized, and their

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15 Van der Ven, *Aan de wieg van Rijkswaterstaat*, chapters II, III and VI; A. Bosch and G. P. van der Ven, 'Rivierverbetering', in H. Lintsen *et al*,. eds., *Techniek in Nederland. De wording van een moderne samenleving 1800–1890*, Zutphen: Walburg Pers, 1993, pp. 103–27.

16 Paul van den Brink, '*In een opslag van het oog*'. *De Hollandse rivierkartografie en waterstaatszorg in opkomst, 1725–1754*, Alphen aan den Rijn: Canaletto, 1998, pp. 42–3, 68–87.

17 Joel Mokyr, *The Gifts of Athena. Historical origins of the knowledge economy*, Princeton: Princeton University Press, 2002, pp. 4–5, 10.

works became the canons of later generations of hydraulic officials'.[18] The first survey of waterways that has survived to the present day has been dated by Needham to the third century AD. The number of books in this field sharply increased from the time of the Song dynasty onwards. Half a dozen works wholly or partly devoted to river control are known from the eleventh and twelfth centuries.[19] The great, classic compendia were produced in the late Ming and early Qing dynasties. Pan Jixun's *Hefang yilan* (An overview of river defence), composed in 1590, was still regarded as a 'standard guide' in the late eighteenth century. Jin Fu's *Zhi he fanglue* (Methods of river control), presented to the court in 1689 but not printed until 1767, 'long exerted great authority'. Many more works followed in the eighteenth century.[20] What appears to have been lacking, though, was the development of a kind of abstract reflection on the subject. These writings on river management are usually described as collections of recipes, procedures, regulations and work rules, based on accumulated experience, rather than as theoretical treatises.[21] None of them seems to have presented a general theory on the motion of fluids, which might, in Mokyr's terms, have served as a 'cognitive base' for techniques of water control. The second form of propositional knowledge, in short, did not come about.

That was precisely what happened in Northern Italy. During the seventeenth century, Cesare Maffioli has shown, this region *did* see a fundamental change in the nature of propositional knowledge. Like the Chinese regions discussed above, Northern Italy possessed not only an oral culture of transmission of knowledge,[22] but also boasted a long tradition of writings about rivers and river control. Studies about the effects of the outfall of rivers on the lagoon of Venice, for example, started to appear from the mid-fifteenth century onwards. The views of engineer Christoforo Sabbadino, laid down around 1550 in his *Discorsi per la laguna di Venezia and Instruzione … circa questa laguna*, acquired the same paradigmatic status with generations of hydraulic experts in the Venetian Republic as the works of Pan Jixun and Jin Fu in China.[23]

The novelty in the Italian case was the emergence of a theory on river hydraulics. This theoretical turn, which started in the Papal States in the 1620s and reached the Venetian Republic a few decades later, essentially consisted, as Maffioli put it, in reshaping the existing tradition of fluvial hydraulics 'in a geometric fashion, around the basic concept of velocity', in order to obtain more reliable knowledge about the motion of waters in rivers.[24] Its founding father was a Benedictine monk who taught mathematics at Pisa and Rome, Benedetto Castelli. Castelli's treatise *Della misura dell'acque correnti* with its companion piece *Demostrazioni geometriche della misura dell'acque correnti*, published in Rome in 1628, for the first time approached the phenomenon of the behaviour of rivers with the full panoply of definitions, suppositions, propositions and demonstrations, which was

18 Dodgen, *Controlling the Dragon*, pp. 7–8, 22.
19 Needham, *Science and civilisation*, pp. 324–5.
20 Dodgen, *Controlling the Dragon*, p. 20, 178; Needham, *Science and civilisation*, pp. 325–6.
21 Flessel, *Der Huang-ho*, p. 1; Needham, *Science and civilisation*, pp. 325–9; Vermeer, 'P'an Chi-hsün's', p. 35.
22 Ciriacono, *Acque e agricoltura*, pp. 142–3.
23 Ciriacono, *Acque e agricoltura*, pp. 148–53, 163.
24 Maffioli, *Out of Galileo*, pp. 419–20.

known as the 'geometric' way.[25] This 'geometrical' approach of river hydraulics was extended in the following decades by the combined efforts of a host of other Italian scholars, including Evangelista Torricelli, Geminiano Montanari, Domenico Guglielmini, Guido Grandi, Bernardino Zendrini and Giovani Poleni, into an elaborate corpus of general concepts, principles and laws relating to the motion of waters. Maffioli observed that around 1700 many Italian contributions to the European scientific debate 'were directly or indirectly related to the science of waters'.[26]

The 'science of waters' by then had received recognition as an autonomous academic discipline by the establishment of a chair of 'hydrometry' at the university of Bologna in 1694. At the university of Padua, around 1710, 'showing a mastery in the subject of waters' was 'a particularly suitable qualification' for an appointment to the chair of mathematics. At the end of the seventeenth century, hydraulics was included in the teaching of mathematics in several Jesuit colleges in the Po valley, too, and sometimes even special courses on the subject of waters were provided. University-educated mathematicians from about 1680 onwards began to instruct and examine in Venice and Bologna candidates for local offices in practical water control (called *periti* or *proti*).[27] Teaching about hydraulics was at this time in Northern Italy clearly no longer confined to training on the job.

The Netherlands did not immediately follow the Italian example. Inspector-General of the Rivers Christiaan Brunings observed in 1771 that the Dutch possessed an abundance of 'practical knowledge' about hydraulics, but that 'the reflective part of these sciences' had hardly been cultivated.[28] Although his remark was a bit unfair to the hydraulic expert Cornelis Velsen, who had published a theoretically ambitious treatise about rivers and river control twenty years before,[29] it was generally true in so far as nearly all writings on this subject composed before the 1770s were either of the prescriptive sort (instructions on how to deal with specific hydraulic problems) or of the propositional category of observations, classifications and measurements of natural phenomena. By the end of the seventeenth century, it had become normal practice among surveyors or engineers, for instance, to put forward proposals to solve the problem of the distribution of water of the Rhine in the form of written memoranda, often accompanied with maps, which were based on rules derived from experience as well as from a series of soundings and careful observations of the situation on the spot.[30] From the 1720s onwards, the surveyor Nicolaas Cruquius brought this approach a major step further, by grounding every proposal, advice or statement about hydraulic matters on an extensive base of measurements of hydraulic variables and making as much use as possible of cartographic aids to record and analyze the resulting data. Other experts soon followed his example.[31]

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25 Maffioli, *Out of Galileo*, pp. 41, 45–51.

26 Maffioli, *Out of Galileo*, p. 14, and Tables 1.1. and 1.2.

27 Maffioli, *Out of Galileo*, pp. 247–9, 276–7, 337, 426.

28 Quoted in P. van Schaik, *Christiaan Brunings 1736–1805. Waterstaat in opkomst*, Zutphen: Walburg Pers, 1984, p. 78.

29 Cornelis Velsen, *Rivierkundige verhandeling, afgeleid uit waterwigt en waterweegkundige grondbeginselen, en toepasselijk gemaakt op de rivieren den Rhijn, de Maas, de Waal, de Merwede en de Lek*, Amsterdam: Isaac Tirion, 1749. His contribution to the theory of hydraulics is briefly discussed in Hunter Rouse and Simon Ince, *History of hydraulics*, Iowa: Iowa Institute of Hydraulic Research, 1957, p. 117.

30 Van der Ven, *Aan de wieg van Rijkswaterstaat*, pp. 64–102.

31 Van den Brink, '*In een opslag van het oog*', chapters 1 and 4.

The difference between the Dutch delta and the regions in China was that the corpus of knowledge in the later eighteenth century went on to include 'propositions' of Mokyr's second form, that is statements about 'regularities, principles and "natural laws"'. The beginning of this phase almost exactly coincided with Brunings' critical observation about the lack of reflective power in Dutch hydraulic science. Scientific societies began to stimulate thinking about theoretical aspects of hydraulics from the 1770s onwards. The very first volume of transactions published by the *Bataafsch Genootschap der Proefondervindelyke Wijsbegeerte* in 1774, for example, opened with a treatise running to over 200 pages by a medical doctor Lambertus Bicker about the basic principles of river management and their application in the case of the Dutch Republic.[32] A lively public debate on issues related to river control ensued, in which the participants did their best to bolster their positions with theoretical arguments. In contrast with China, education about hydraulic matters did not remain confined to training on the job or to the individual perusal of writings of famous predecessors. Johan Frederik Hennert, professor of mathematics, astronomy and physics at the University of Utrecht, began to offer 'public lectures on the course of rivers' from the 1780s onwards. At the University of Leiden, hydraulics was taught by Jan Frederik van Beeck Calkoen, who held the chair of natural philosophy from 1799.[33] Pupils at the privately endowed Fundatie van Renswoude in Delft who chose to become hydraulic engineers, received at that time both a training 'on the job' and a thorough grounding in mathematics and physics from teachers at the institute itself.[34]

Knowledge and socio-political structures

The comparative survey of the development of knowledge on river hydraulics presented above leads to two intriguing questions. Why did the cognitive leap in this field of knowledge occur in Northern Italy rather than in any of the regions in China? And why did the Rhine delta, in contrast to the two regions in China, offer such a receptive environment to this new approach in fluvial hydraulics from about 1770 onwards? These are the key issues to be addressed in the final section of this article.

The breakthrough in river hydraulics that began in Northern Italy in the second quarter of the seventeenth century was, to some extent, related to the indigenous tradition of hydraulic engineering that had flourished in Italy from the Renaissance onwards. Benedetto Castelli and his followers did not have to start from scratch. They could build on the accumulated knowledge of several generations of hydraulic practitioners. But this was only part of the story. If it had been the whole story, it would be very puzzling indeed why a similar leap was not accomplished in China. Another part of the explanation was that the new approach was from the very start also clearly contrasted with the tradition of the *periti* and *proti*. Champions of the 'science of waters' claimed that their 'geometrical way

32 L. Bicker, 'Rivierkundige grondwaarheden bijzonderlijk toegepast op de rivieren onzes lands tot herstelling derzelven', *Verhandelingen van het Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte*, 1, 1774, pp. 1–210.

33 Maffioli, 'Italian hydraulics', 250, *Nieuw Nederlandsch Biografisch Woordenboek*, vol. IX, Leiden: Sijthoff, 1937, pp. 123–4.

34 E. P. De Booy and J. Engel, *Van erfenis tot studiebeurs. De Fundatie van de vrijvrouwe van Renswoude te Delft*, Delft: Meinema, 1985 , pp. 72–81, 105–12.

of thinking' would generate more reliable, and therefore more useful, knowledge than the empirical approach of the practical experts. The origin of this theoretical turn should, according to Maffioli, be sought in the extension of Galileo's mathematical approach to nature, initially developed to study the motion of solid bodies, to the domain of the motion of waters. The 'new science' of Galileo thus acquired a wider field of application. And Castelli was in an unique position to forge the link because he was a hydraulic consultant of the papal court, and a mathematics professor as well as one of the closest collaborators of Galileo himself.[35] This does not imply that the new departure in river hydraulics consisted entirely in the transplantation of Galilean concepts and methods. Later generations of scholars made important additional contributions to the field by applying new intellectual tools such as the calculus and refining the use of experiments.[36] The key change, in retrospect, was the fusion of insights from two different traditions of knowledge, which provided the field of river hydraulics eventually with a more extended, varied set of propositions about nature than the *periti* and *proti* alone would have been able to muster.

The change in the body of knowledge on river control in the Netherlands during the eighteenth century was partly related to the direct or indirect influence of the Italian model, and partly to growing contacts between the worlds of academic learning and hydraulic engineering in the Netherlands itself. The influence from the Italian example became increasingly noticeable after c. 1720. It was transmitted through movements of people as well as by the spread of knowledge stored in printed works. The Italian engineer and founder of the Institute of Arts and Sciences in Bologna, Luigi Fernando Marsigli, for instance, who was a long-time correspondent of Boerhaave, resided for over a year in Holland in 1722 and 1723. During his stay, he made several trips along the hydraulic 'sights' in the coastal provinces in the company of Boerhaave and Cruquius. It was the Italian visitor who inspired Cruquius to introduce curves of equal depths in river maps about 1730, which became a normal feature in the cartography of rivers in the Dutch Republic from then on.[37] Another Italian hydraulic scientist of note, Paolo Frisi, who held the chair of mathematics and philosophy in Milan, kept up lasting contact with Dutch colleagues after a journey to the Netherlands in 1766.[38] A Dutch translation of a short treatise by Frisi on the division and confluence of rivers, which was partly based on theoretical insights and practical experiences gained by experts in Italy as a result of the long-drawn out debate on the regulation of the river Reno, appeared in the transactions of the *Hollandsche Maatschappij* in 1773.[39] Dutch academians and engineers also learned about advances in hydraulic phenomena in Italy simply by studying their books. 's Gravesande, for instance, was thoroughly acquainted with the work of, among others, Guglielmini, Grandi and Poleni. Theoretical insights and methods developed by Guglielmini and Poleni served as a source of inspiration

35 Maffioli, *Out of Galileo*, pp. 37–51, 418–23.

36 Maffioli, *Out of Galileo*, parts III and IV.

37 Van den Brink, '*In een opslag van het oog*', p. 59; A. McConnell, 'A profitable visit: Luigi Fernando Marsigli's studies, commerce and friendships in Holland, 1722–23', in Maffioli and Palm, eds., *Italian scientists*, pp. 189–207.

38 Maffioli, 'Italian scientists', pp. 257–8.

39 'Berigt aan de Hollandsche Maatschappij der Weetenschappen van Paulo Frisi nopens de verdeeling en zamenloop der rivieren', *Verhandelingen uitgegeeven door de Hollandsche Maatschappij der Wetenschappen*, XIV, 1773, pp. 112–30.

to Hennert and Brunings in the 1780s.[40] When his regular bookseller failed him, Brunings did his utmost to get hold of Italian publications about hydraulics through his connections in the literary world.[41] By the end of the eighteenth century the work of French hydraulicians, who brought the approach pioneered in Italy to an even higher degree of elaboration and refinement, began to exert a growing impact on the Netherlands as well. Brunings' future successor Jan Blanken Jansz. in 1797 made a technological journey through France, during which he bought a large part of the library on hydraulic engineering that served him for the rest of his life, and made the acquaintance of a number of leading French engineers.[42]

Beside the direct or indirect influence from the Italian model, growing contact between the worlds of academic learning and hydraulic engineering in the eighteenth century led to the transformation in the body of knowledge on river control in the Netherlands. A telling example of this increased contact is the fact that all the leading hydraulic experts in the middle decades of the century—Cruquius, Velsen, Melchior Bolstra and Dirk Klinkenberg—not only received training on the job, but also studied for a while at the university of Leiden. Cruquius matriculated in 1717 as a student in medicine, Velsen in 1727 and Bolstra in 1732 as students in surveying at the *Duytsche mathematicque* (an adjunct of the university, providing vernacular courses for surveyors and engineers), Klinkenberg in 1751 as a student in astronomy and geometry.[43] Leiden professors, on their part, were since the 1720s repeatedly asked by the States of Holland to act as advisors on projects for river improvement. After 1754 this relationship assumed a more institutional form by the appointment of Klinkenberg's Leiden teacher, professor Johan Lulofs, as Inspector-General of the Rivers in Holland.[44] The results of the increased connections between the worlds of academic learning and hydraulic engineering can be traced in the work of experts such as Cruquius or Velsen. Cruquius's comprehensive, quantitative and highly systematic approach to problems of river improvement (and other issues in hydraulic technology) was influenced by, among others, the Leiden professors Herman Boerhaave, the guiding star in European medicine in the first half of the eighteenth century, and Willem Jacob 's Gravesande, who after his accession to the chair of mathematics and astronomy in Leiden in 1717 quickly became the foremost champion of Newtonian science on the Continent.[45] Cornelis Velsen's *magnum opus* on river management published in 1749, *Rivierkundige verhandeling*, betrayed not only an extensive knowledge gained from practical experience in grappling with the problems of the Merwede, the Waal and the Lek, but also a thorough acquaintance with general publications on hydrodynamics and with Newtonian science as

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40 Maffioli, 'Italian scientists', pp. 238, 252–3; van Schaik, *Christiaan Brunings*, pp. 12–16, 56–8, Christiaan Brunings, 'Antwoord op de vraag . . .: Is de algemeen grondregel der hydrometrie . . . insgelyks toepasselyk op de zeeboezems, gelyk het Ye . . .', *Verhandelingen uitgegeeven door de Hollandsche Maatschappij der Wetenschappen*, 24, 1787, pp. 1–58.

41 Van Schaik, *Christiaan Brunings*, p. 77.

42 Rouse and Ince, *History of hydraulics*, pp. 113–38, *De physique existentie dezes lands: Jan Blanken Jansz. inspecteur-generaal van de waterstaat (1755–1838)*, Amsterdam: AMA, 1987, pp. 11, 15–16, 251–9.

43 Karel Davids, 'Universiteiten, illustre scholen en de verspreiding van technische kennis in Nederland, eind 16e–begin 19e eeuw', *Batavia Academica*, 8, 1990, p. 19.

44 Van der Ven, *Aan de wieg van Rijkswaterstaat*, pp. 266–71; Van den Brink, '*In een opslag van het oog*', pp. 32, 51–2, 62–4, 67–9, 73–5, 138–40.

45 Van den Brink, '*In een opslag van het oog*', pp. 13–18, 24–5.

expounded by 's Gravesande and his colleague Petrus van Musschenbroek.[46] Engineers thus increasingly became carriers of 'propositional' knowledge about fluvial hydraulics themselves.

Exchange between academics and engineers became even more intensive in the second half of the eighteenth century as new channels of communications were opened by the rise of scientific societies like the *Hollandsche Maatschappij* in Haarlem and the *Bataafsch Genootschap* in Rotterdam. Members of these societies were not only recruited from the ranks of academic scholars and amateur scientists or patrons from the political elite, but also from the group of distinguished or promising experts in various fields of technology, such as—in the sphere of hydraulic engineering after 1750—Klinkenberg, Brunings and Blanken. Their meetings, prize questions and publication series created even more opportunities for the spread of various forms of propositional knowledge.

In China, by contrast, the changes in propositional knowledge about river hydraulics emanating from Northern Italy had not exerted any notable impact by the middle of the nineteenth century. Linqing's compendium *Hegong Qiju Tushuo* (An illustrated guide to tools used in river work), published in 1836, betrayed according to Needham 'very little indebted(ness) to Western influences'.[47] There is no obvious reason why the 'geometrical' approach pioneered in Italy could not have been adopted in China in the later seventeenth or eighteenth century as well. China was more distant from the coastal plains of the Po than the Netherlands or France, of course, but it is not evident why in this case mere geographical distance would have thwarted the transmission of knowledge. After all, 'from the late sixteenth to the late eighteenth century [...] Chinese were extremely interested in Europe and all it had to offer', Joanna Waley-Cohen has argued, and she has amply shown how much knowledge about a wide range of subjects in fact *did* find its way from 'the West' to China before 1800. For a long time, the principal intermediaries between Europe and China were the Jesuits, but in the course of the eighteenth century other groups of travellers began to visit the empire as well.[48] If Chinese regions really had offered a receptive environment for the new approach in river hydraulics developed in Northern Italy, it is hard to see how geographical distance alone could have prevented its transmission.

But was the receptivity perhaps lacking, because the problem of flooding for the time being had been brought more or less under control? While this may have been true for the Yellow River delta up to the middle of the nineteenth century (at least from a technical point of view), it was not the case in the basin of the middle Yangzi, where the frequency of flooding dramatically increased from the late 1780s onwards.[49] Moreover, in the Netherlands the receptivity for the new approach in river hydraulics actually increased *after* the frequency of flooding by the Rhine and Meuse had significantly declined.[50] The

46 Velsen, *Rivierkundige verhandeling*, pp. 16–17, 26–7.

47 Catherine Jami, 'Learning mathematical sciences during the Early and Mid-Ch'ing', in Benjamin A. Elman and Alexander Woodside, eds., *Education and society in Late Imperial China, 1600–1900*, Berkeley: University of California Press, 1994, p. 229, Needham, *Science and civilisation*, p. 329.

48 Joanna Waley-Cohen, *The sextants of Beijing. Global currents in Chinese history*, New York/London: W.W. Norton & Co., 1999, p. 128; Joanna Waley-Cohen, 'China and western technology in the late eighteenth century', *The American Historical Review*, 98, 5, 1993, p. 1543.

49 Will, 'Un cycle hydraulique', pp. 282–4.

50 On the frequency of flooding, see the instructive graph in Richard J. Tol and Andreas Langen, 'A concise history of Dutch river floods', *Climate Change*, 46, 2000, p. 368.

urgency of the problem of flooding itself thus does not provide an adequate explanation either.

The lack of receptivity in China to the 'Italian' approach before 1850, I would suggest, was related to the very factors that may explain why the cognitive leap in knowledge in river control was not accomplished there in the first place. If the theoretical turn in Italy indeed, as Maffioli put it, essentially consisted in reshaping the existing tradition of fluvial hydraulics 'in a geometric fashion, around the basic concept of velocity', part of the explanation of its absence in China could have resided in the circumstance that 'deductive geometry in the Western sense' was also lacking. 'Chinese mathematics' after all is said to have been 'rather focused on arithmetical and algebraic procedures'.[51] Yet, there must have been more to the matter than the availibility of particular intellectual tools. The supply of such tools was not an invariable given. Euclidean geometry and various European innovations in methods of calculation *did* reach China through the intermediary of the Jesuits in the course of the seventeenth century.[52] The study of river hydraulics in Qing China thus might have drawn upon similar resources as in Europe. To explain the differences in development, other than intellectual factors must be taken into account as well.

Now, one of the striking features of the evolution in China is that both 'prescriptive' and 'propositional' knowledge about fluvial hydraulics was apparently almost entirely produced *within* the bureaucracy that was concerned with controlling the Yellow River. There were no complementary, or rival, sites of knowledge production and distribution about river hydraulics. River control formed part of the field of activity of the central state in China from a relatively early date, compared to the Netherlands or Northern Italy. A central agency to coordinate efforts to control the Yellow River, the Office of Rivers and Canals, was already established in the middle of the eleventh century. 'The centralization of the management of the resources destined for the handling of the river was shown indispensable once hydraulic operations, whose costs could no longer be borne at the local level, appeared as a new charge in the budgets controlled by the central administration', Christian Lamouroux has observed.[53] In the following centuries the state stepped up the input of resources for the maintenance of the control system of the Yellow River, especially since the management of the river from the 1410s onwards was closely connected to the upkeep of the Grand Canal, which served as the main artery for the supply of foodstuffs and other goods to the capital and army in the North. The north–south route of the Canal namely 'included a portion of the lower course of the Yellow River, a fact that complicated both canal transport and river management', according to Dodgen.[54] Because of its vital importance for the preservation of the state itself, the maintenance of the Yellow River and Grand

51 H. Floris Cohen, *The Scientific Revolution. A historiographical inquiry*, Chicago: University of Chicago Press, 1994, p. 440, following Joseph Needham, *The Grand Titration. Science and society in East and West*, London: Allen & Unwin, 1969, p. 44.

52 Jami, 'Learning mathematical sciences', pp. 229–31, Benjamin A. Elman, *From philosophy to philology. Intellectual and social aspects of change in Late Imperial China*, Cambridge MA: Harvard University Press, 1984, pp. 180–4.

53 Christian Lamouroux, 'From the Yellow River to the Huai. New representations of a river network and the hydraulic crisis of 1128', in Mark Elvin and T.-J. Liu, eds., *Sediments of time. Environment and society in Chinese history*, Cambridge: Cambridge University Press, 1998, pp. 545–84, 559–60.

54 Dodgen, *Controlling the Dragon*, p. 15.

Canal system became one of the principal preoccupations of the imperial bureaucracy. The efforts to keep the control system intact, despite the growing problems caused by the steady accumulation of silt left by the river, were not abandoned until the middle of the nineteenth century, when the Qing state for fiscal and political reasons 'could no longer afford to keep [it] operating'.[55]

The technical management of the system was undertaken by an ever-expanding hydraulic bureaucracy, assisted by provincial officials for the organization and supervision of maintenance and repair jobs at a local level. The top positions in this bureaucracy were in the Qing period increasingly filled with people who had risen through the ranks and thus had acquired a high degree of specialization in river hydraulics.[56] Private secretaries, hired by high-level officials to conduct the daily business of administration, could possess a particular competence in this field as well.[57] This elaborate official or unofficial bureaucratic structure did not preclude the emergence of divergent views about practical ways to solve the problems of managing the Yellow River—witness the intense debates and dramatic shifts in policy in the time of Pan Jixun at the end of the sixteenth century or during the tenure of Jin Fu as Director General of the Conservation of the Yellow River in the 1680s.[58] The degree of institutional concentration of the production and distribution of knowledge on river hydraulics realized in China was nevertheless much higher than in either of the two regions in Europe, which may have made the rise of new, different forms of propositional knowledge far less easy.

The expansion of the hydraulic bureaucracy in China clearly had much to do with the fact that the problem of controlling the Yellow River had become inextricably connected with that of managing the chief supply route to the capital of the Empire, the Grand Canal. In the basin of the middle Yangzi, where such a direct connection did not exist,[59] the role of this bureaucracy was much more subdued. Although government subsidies were a significant stimulant to the extension and improvement of dike construction in the plains of Hubei, Hunan and Jiangxi during the Song, the early Ming and the reign of emperor Kangxi (1661–1722), state control of river management in this area did not reach the same level of intensity as in the case of the Yellow River basin. Local communities and private individuals always took—legally or illegally—a large share in dike building and dike repair.[60] Supervision by higher officials was strengthened after a disastrous flood in 1788, but these measures did not result in a permanent growth of bureaucratic power in hydraulic affairs in this region.[61]

The study of river hydraulics in China still might have gone through a similar cognitive leap as in Northern Italy, if the knowledge accumulated by experience at a local level had

55 Dodgen, *Controlling the Dragon*, p. 159.

56 Dodgen, *Controlling the Dragon*, pp. 22–4.

57 Pierre-Étienne Will, 'Bureaucratie officielle et bureaucratie réelle. Sur quelques dilemmes de l'administration impériale à l'époque des Qing', *Études Chinoises*, 8, 1, 1989, pp. 83–4; Dodgen, *Controlling the Dragon*, p. 151.

58 See note 11 and Richard E. Strassberg, *The world of K'ung Shang-Jen. A man of letters in Early Ch'ing China*, New York: Columbia University Press, 1983, pp. 118–20, 350–1.

59 There was an indirect connection in the sense that this region since the early sixteenth century became an important exporter of rice, which found its way down the Yangzi and thence could reach the Grand Canal.

60 Will, 'Un cycle hydraulique', pp. 268–81; Perdue, 'Water control', pp. 752–9.

61 Perdue, 'Water control', pp. 759–61.

been reshaped into a system of more abstract, generalized 'science of waters' in the context of the private academies, which—with permission of the Emperor—sprung up in large numbers in the Lower Yangzi area during the eighteenth century. These private academies offered an alternative route for higher education to the imperial school system, and provided a fertile environment for the flowering of so-called 'evidential' scholarship, i.e., research aimed at recovering and restoring past Confucian learning by rigorous, critical study of classical sources. A revival of mathematical studies formed part of this 'evidential' movement.[62] Yet, there is no indication that scholars in these institutions made an effort to develop a mathematical approach to the field of fluvial hydraulics. They were not interested in applying their knowledge to a practical concern like the study of rivers.[63] A rival centre for the production and distribution of knowledge on river hydraulics in reality did not emerge.

The organization of river management in the Rhine delta was for a long time not unlike that in the basin of the middle Yangzi. River defence at first rested almost exclusively in the hands of local or regional water boards. It was not until the end of the seventeenth century that provincial governments in the Netherlands began to play a more active role in efforts at river control and the degree of cooperation and coordination between individual provinces in this sphere of activity gradually increased. Still, provincial authorities exerted only a limited influence on the technical solutions that were chosen in each particular case. When the interests of the various parties involved diverged too much, and no party possessed a clear ascendancy over the others (financially or otherwise), the result could be a complete stalemate. This was what eventually occurred, for instance, in the case of attempts to control the river Merwede between Gorinchem and Dordrecht in the 1730s. The difference of interest between the cities in Holland that had a stake in the solution of the problem (Gorinchem, Dordrecht, Rotterdam, Schiedam, Delft and Brielle) in the end proved too large to be bridged by some ingenious, laborious compromise.[64] As a result, the development of technical means and devices to cope with the issue in this particular case remained stuck for years as well. The tardiness of active management at a higher level than that of local or regional water boards is also reflected in the fact that the leading province of the Dutch Republic, Holland, did not begin to allocate substantial sums of money for investments in river control on a regular basis until the late 1730s. More than three-quarters of the expenses for the works of redirecting the river Rhine were up till then paid by the Gelderland and Utrecht. The largest projects, the construction of the *Bijlands Kanaal* and of the huge groyne at the point of separation between the Waal and the *Pannerdens Kanaal* in 1776 and 1784 respectively, were financed for more than 70% by the province of Holland, however.[65] A central bureaucracy in river management in the Netherlands did not come into being until the very end of the eighteenth century. The Dutch

62 Elman, *From philosophy to philology*, pp. 7–36, 79–80, 105–6, Alexander Woodside, 'The divorce between the political center and educational creativity in Late Imperial China', in Elman and Woodside, eds., *Education and society in Late Imperial China*, pp. 476–85.

63 Cf. Jami, 'Learning mathematical sciences', p. 227.

64 Van den Brink, '*In een opslag van het oog*', chapter 3.

65 W. Fritschy and R. Liesker eds, *Gewestelijke financiën ten tijde van de Republiek der Verenigde Nederlanden, vol. IV Holland (1572–1795)*, The Hague: SDU, 2004, pp. 454–5; Van der Ven, *Aan de wieg van Rijkswaterstaat*, p. 363.

counterpart of the Office of Rivers and Canals, *Rijkswaterstaat*, was finally established in 1798.[66]

Expertise on river hydraulics in the Netherlands accordingly showed a lower degree of institutional concentration than in China. Producers and distributors of knowledge on this subject could be found at a variety of places. Apart from 'independent scholars' such as Christiaan Huygens and Johannes Hudde, who were in the 1670s and 1680s occasionally asked for advice by the provincial government of Holland, the array of experts also included small groups of surveyors or engineers employed by provincial administrations, regional water boards or urban governments and a number of professors at the universities of Leiden and Utrecht. The relative lateness of centralization in river management, plus the diversity in the social and institutional basis of knowledge on fluvial hydraulics, allowed a smooth adoption of the 'Italian model', once this approach in the course of the eighteenth century was transmitted to the Netherlands. Resistance from vested interests could hardly occur. The timing of this shift in knowledge itself was largely determined by the growing interference of the provincial government of Holland and the powerful water board of Rijnland with the field of river management, and by the increased interest among scholars at institutes of higher learning, which became manifest in the second quarter of the eighteenth century, in studying practical, technical problems.[67]

The unique feature of the North Italian case, I would suggest, was a combination of a relative precocity in the bureaucratic organization of river management with much diversity in social and institutional basis of knowledge on fluvial hydraulics. As in China, hydraulic administrators appeared relatively early, but the production and distribution of knowledge on the subject was much more dispersed. This special combination of elements meant, on the one hand, that a novel form of propositional knowledge could emerge earlier in Northern Italy than in the Netherlands, but implied, on the other hand, that there was a greater need for reasoned (or rhetorical) justification of this new approach to old problems.

Hydraulic offices could be found at an early date in several states and cities in Northern Italy. In Venice, for instance, a magistracy for the supervision of canals was instituted in 1224. A *Magistrato all' Acqua*, responsible for handling all hydraulic problems, was established in 1501.[68] Another office, charged with taking care of the river Adige, was erected in 1677, with branch offices in Verona and Padua. The managers of these boards, who were members of the Venetian patriciate, could call on a small staff of technical experts, the *proti*.[69] Experts from Venice were in the late sixteenth century repeatedly called upon to advise on the solution of hydraulic problems in the environs of Ferrara.[70] Bologna founded a hydraulic board, too, called the *Assunti* to the waters. These *Assunti*, recruited

66 A. Bosch and W. van der Ham, *Twee eeuwen Rijkswaterstaat 1798–1998*, Zaltbommel: Europese Bibliotheek, 1998.

67 Davids, 'Universiteiten', pp. 11–23.

68 Ciriacono, *Acque e agricoltura*, p. 140, Frederic C. Lane, *Venice. A maritime republic*, Baltimore: The Johns Hopkins University Press, 1973, p. 16.

69 Maffioli, *Out of Galileo*, pp. 276–7.

70 Alessandro Fiocca, 'Regolamentazione delle acque e transfert tecnologico nel tardo Rinascimento. Il caso di Ferrara e Venezia', in A. Fiocca, D. Lamberini, and C. S. Maffioli, eds., *Arte e scienza delle acque nel Rinascimento*, pp. 139–41.

from the Senate, likewise received assistance from a staff of practical experts, the *periti*. Another post, superintendent of the waters around the city, was established in 1686.[71]

Knowledge on river hydraulics did not remain confined to these special offices concerned with water control, however. Other sites of knowledge production and transmission in the seventeenth century arose at Jesuit colleges and universities. It was at these institutes for higher learning, which were not dependent on the old-established hydraulic offices, that the theoretical turn in fluvial hydraulics first occurred. *Proti* and *periti* were, naturally, neither overjoyed by its appearance, nor quickly convinced of its use. The rise of these rival centres of knowledge was apparently the outcome of three parallel developments. One of the driving forces was the growing competition for students between the university of Bologna and Jesuit colleges as well as other institutes of higher learning in the Papal States. Faced with a serious crisis caused by the diminishing attractiveness of the local university to foreign students and the local nobility, the municipal government of Bologna (as supervisor of this institution) actively welcomed innovation in the curriculum in the later seventeenth century. At the same time, the new approach in hydraulics could also make headway at the state university of the Venetian Republic in Padua, thanks to the support of the Venetian patricians, who set great store on the knowledge of the newly risen 'scientists of the waters' as an alternative source of expertise to the traditional lore of technical practitioners.[72] For scholars themselves, employment at a university became more attractive as an avenue to make a career in science, as opportunities for patronage from princely courts declined. In that sense, too, Italian scholars after Galileo struck out into a new direction.[73]

Conclusion

This essay has compared the development of knowledge on river hydraulics between about 1400 and 1850 in four regions in China and Europe: the coastal plains of the Yellow River, the basin of the middle Yangzi, the coastal area of Northern Italy and the Rhine delta in the Netherlands. River hydraulics was a field of knowledge that in the eyes of contemporaries—witness the growing input of money, manpower and materials—was obviously eminently 'useful'. Knowledge on river hydraulics was in each of these regions considered to be highly important for the protection of society against natural disasters and threats from external human enemies, for the maintenance of wealth and for the preservation of state institutions and political power.

The comparison has shown that the evolution of the body of knowledge in the four regions was up to a point quite similar. Each of these regions saw the emergence of sets of both prescriptive and propositional knowledge which on the one hand formed the basis for technical manipulations of the natural environment and on the other hand, through feedback mechanisms, expanded by the incorporation of observations and experiences accumulated in the actual practice of water control. But the developments

71 Maffioli, *Out of Galileo*, pp. 172, 181–2.

72 Maffioli, *Out of Galileo*, pp. 132–5, 243–9, 274–7; Paolo Buonora, 'Cartografia e idraulica del Tevere (secoli XVI–XVII)', in A. Fiocca, D. Lamberini, and C. S. Maffioli, eds., *Arte e scienza delle acque nel Rinascimento*, p. 178.

73 Maffioli, *Out of Galileo*, chapter 6 and pp. 422–8.

diverged in the nature of the propositional knowledge that was produced and transmitted. Northern Italy in the seventeenth century saw an cognitive leap from 'observations, classifications, measurement and cataloguing of natural phenomena' to another form of propositional knowledge, namely 'the establishment of regularities, principles and "natural laws"', and the Netherlands after a while adopted this 'Italian' model. The origins of this cognitive transformation lay in the grafting of a mathematical ('Galilean') approach to nature onto an existing tradition of engineering. An existing body of knowledge was reinterpreted from a new angle of vision. The combination of 'new science' with 'old practice' thus changed the nature of 'useful' knowledge. In China, however, no such theoretical turn in river hydraulics occurred before 1850. In the last part of this essay I extended the comparison to contextual factors to answer the questions why the cognitive leap in this domain of knowledge began in Northern Italy, rather than in the coastal plains of the Yellow River or the basin of the middle Yangzi, and why the Rhine delta in the eighteenth century provided a more a receptive environment to this new approach in fluvial hydraulics than any of the regions in China.

Sheer geographical distance, a seemingly diminished urgency of the problem of flooding or a supposed dearth of particular intellectual tools proved not to offer an adequate explanation for this divergence in the evolution of knowledge between the regions in China and Europe. However, the contextual comparison revealed some important differences in the underlying socio-political structures of the creation and transmission of knowledge. The degree of institutional concentration of knowledge on river hydraulics was much higher in China than in either of the two regions in Europe. In contrast with China, the production and distribution of knowledge on this subject in Northern Italy and the Netherlands was spread over a variety of sites, which could serve as a base for different groups of experts who could challenge, or even transform, dominant cognitive traditions both at the 'prescriptive' and 'propositional' level. Greater diversity in social and institutional bases, I suggested, increased the potential for cognitive breakthroughs and enhanced the receptivity for new approaches developed elsewhere.

This brings us to a final point which emerges from the comparison between China and Europe. In the European regions examined in this article, the variety of sites for the production and distribution of knowledge also included universities and similar institutes of higher learning. Both in Northern Italy and in the Netherlands, universities during much of the seventeenth and eighteenth centuries were important centres for the creation and transmission of 'useful' knowledge at large—not just knowledge in natural philosophy, medicine or law. The impetus for this growing interest in 'useful' knowledge at these institutes for higher learning came both from scholars themselves and from the demand exerted by public authorities. The private academies that proliferated in eighteenth-century China, by contrast, in the case of river hydraulics apparently did not play the same role as did these European institutes. The question of whether this difference also existed in other domains of knowledge and if so, why it emerged, surely deserves further study.

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